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THE SHAGAWA LAKE PROJECT. LAKE RESTORATION BY NUTRIENT REMOVAL FROM WASTEWATER EFFLUENT

Kenneth W. Malueg, et al

Pacific Northwest Environmental Research Laboratory

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The Shagawa Lake Project

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THE SHAGAWA LAKE PROJECT

LAKE RESTORATION BY NUTRIENT REMOVAL FROM WASTEWATER EFFLUENT

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January 1973

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INTRODUCTION

The progressive enrichment of a body of water with aquatic plant nutrients and the response of this body of water in terms of increased biological production and its consequences is known as eutrophication. Lakes typically evolve from a state of low productivity and relative purity to one of increased productivity and lessened quality, often culminating in nuisance algal growths, drastically reduced oxygen content, and noxious tastes and odors. Under natural conditions this is a lengthy process, requiring perhaps hundreds or thousands of years. Where a lake is subjected to heavy human population pressure, however, eutrophication proceeds much more rapidly. Human waste disposal greatly increases the rate of flow of nutrients into lakes and thereby profoundly affects the rate and extent of the eutrophication process. This phenomenon is known as accelerated or cultural eutrophication and constitutes a major environmental problem.

In recent years scientists and laymen alike have expressed concern with the deteriorating quality of our aquatic resources. Their demands for action have prompted investigations of lake restoration techniques effective in reversing the tendencies of lakes to be overly productive.

Lake restoration techniques which have shown promise in pilot or full-scale demonstrations include diversion of wastewater effluent around a lake, in situ chemical treatment of a lake to precipitate nutrients, aeration, and dredging. Another technique thought to hold promise but not yet scientifically studied is that of advanced wastewater treatment. The objective of the Shagawa Lake Project is to demonstrate the restoration

of a eutrophic lake by removing a critical algal growth-promoting nutrient--phosphorus--by advanced treatment of municipal wastewater while permitting such treated effluent to continue to flow into the lake. If this project is successful, the technique could be applied worldwide to many eutrophic lakes.

HISTORY OF THE DEVELOPMENT OF SHAGAWA LAKE RESTORATION PROJECT

Numerous potential lakes were investigated to select an appropriate site to demonstrate the restoration of a eutrophic lake by the utilization of advanced wastewater treatment. Shagawa Lake was chosen for the following reasons: 1) it had a history of algal blooms; 2) there was no significant agriculture and industry in the area; hence, municipal wastewater was the major source of nutrients to the lake; 3)the eutrophic state of the lake was uncommon among the lakes in northeastern Minnesota; 4) the major surface flow of water to Shagawa Lake, Burntside River, came from oligotrophic (low nutrient) Burntside Lake; and 5) the water quality of Shagawa Lake is particularly important because its outflow passes through parts of the Superior National Forest, the Boundary Waters Canoe Area, and Canada.

The Shagawa Lake restoration project in Ely, Minnesota, was initiated in 1966 by the Federal Water Pollution Control Administration, a predecessor of the Environmental Protection Agency. Before construction of a full-scale advanced wastewater treatment system, primarily to remove phosphorus, it was necessary to show, on a pilot scale, that wastewater so treated would not promote excessive growths of algae when mixed with lake water. Therefore, in 1966 a pilot plant to remove phosphorus from a portion of the municipal wastewater from the City of Ely was constructed and its effluent tested to demonstrate its low algal growth-promoting capability.

Additionally, a limnological investigation was initiated to document the trophic state of the lake.

Based upon the results of the pilot phase studies, the Environmental Protection Agency in 1971 funded a full-scale advanced wastewater treatment system. The treatment plant began operation in early 1973. The rate and extent of recovery of the lake will be documented by continuing studies for several years to obtain limnological data. Background data describing biological, physical, and chemical characteristics of the lake will be used in determining the validity of several mathematical models which will be developed in an attempt to describe the eutrophic process. Hence, a portion of future activities will be devoted to the mathematical modeling of Shagawa Lake and to simulating the changes expected by advanced wastewater treatment.

GENERAL DESCRIPTION OF SHAGAWA LAKE

Shagawa Lake, (Fig. 1), located adjacent to the City of Ely (population 5000) in northeastern Minnesota, about 80 miles north of Duluth, was formed, along with numerous other lakes in the region, during the retreat of the Wisconsin Glacier approximately 10,000 years ago. It has a surface area of about 2400 acres, a maximum depth of 45 ft., and an average depth of about 20 ft. Its major tributary, Burntside River, enters the lake from the west, flowing out of nearby oligotrophic Burntside Lake; several small tributaries drain the adjacent terrain; Shagawa River, the only outlet, leaves the eastern edge of the lake and enters Fall Lake within a few miles.

In contrast to the many oligotrophic lakes in this area of Minnesota, Shagawa Lake is eutrophic. Since natural sources of growth-promoting nutrients are low, the high productivity of Shagawa Lake has been

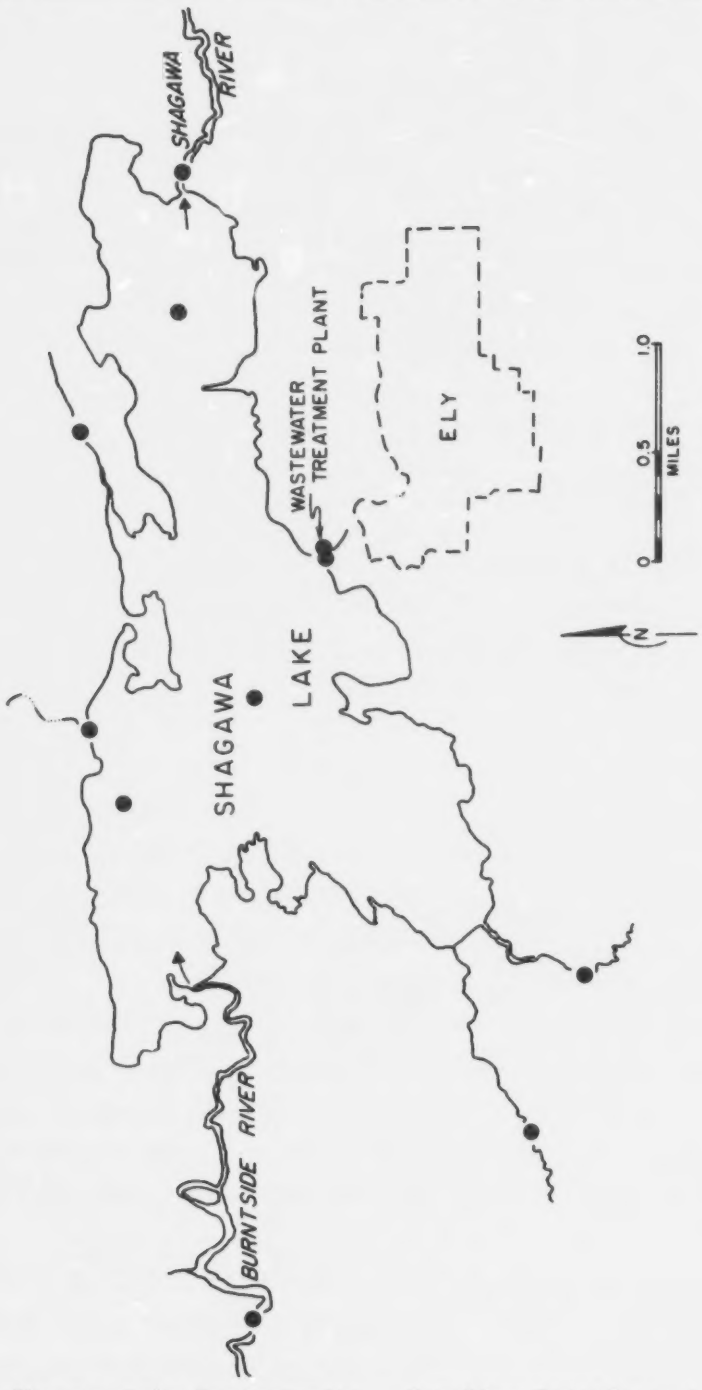


FIGURE 1 Shagawa Lake Project site. Sampling locations shown as ●

attributed to the nutrients entering it from the City of Ely municipal wastewater which has been discharged to the lake since before 1900. Originally, Shagawa Lake was the source of drinking water for the town's populace, but as early as 1932, contamination had increased to such a level that the town was forced to obtain water from Burntside Lake. Primary wastewater treatment was employed until 1954 when a secondary treatment system (high-rate trickling filter) was installed. Neither of these treatment processes removes significant amounts of nutrients.

ADVANCED WASTEWATER TREATMENT PILOT PHASE

In 1966, under supervision of the Pacific Northwest Water Laboratory, Corvallis, Oregon (Federal Water Pollution Control Administration), the pilot phase of the lake restoration demonstration study at Shagawa Lake was initiated. This phase of the project employed a 28,000 gallon-per-day advanced wastewater treatment plant.

The pilot plant was designed to provide chemical treatment, flocculation, settling, filtration, ion exchange, and activated carbon adsorption. Most impurities could thus be removed from the municipal secondary wastewater entering this pilot plant. It was determined from these studies that over 99 percent of the phosphorus was removed by the chemical treatment, flocculation, settling, and filtration processes leaving a residual phosphorus concentration of 0.05 mg/l or less (Table 1).

ALGAL GROWTH POTENTIAL STUDIES

During the pilot phase, studies were undertaken to determine the algal growth potential of Shagawa Lake water. Experiments on the effects of treated municipal wastewater on natural lake waters were conducted in

TABLE 1 Analytical values[a], mg/l, of effluent from tertiary sewage treatment pilot plant. (From Brice, et al., 1969)

Analysis	Sample Source[b] SE	CF	Cumulative % Removal	CE	CC	AE	Cumulative %Removal
Total PO_4-P	5.6	0.05	99.1	0.05	0.04	0.01	99.8
Ortho PO_4-P	4.9	0.04	99.2	0.02	0.02	< 0.01	99.8+
Kjeldahl-N	16.3	16.3	0	3.7	2.8	2.6	84
NH_3-N	13.0	11.4	12.3	0.6	0.3	0.3	97.7
NO_3-N	1.2	1.3	none	0.6	0.06	0.05	95.8
Na	27.3	30.9	none	2.2	2.5	1.5	94.5
K	8.0	7.0	12.5	0.5	0.5	0.4	95
Fe	0.8	0.2	75	-	-	0.03	96.2
Sol. SiO_2	8.1	7.3	9.9	7.7	7.7	0.4	95
TDS	217	269	-	186	177	19	91.2
Total Hard.	94.5	101.4	-	0	0	0	100
Ca Hard.	76.6	83.7	-	0	0	0	100

[a]Averages from 6 weeks operation - approximately 500,000 gallons through flow.

[b]SE = effluent from trickling filter sewage plant.

CF = effluent from chemical-coagulation-filtration step effluent.

CC = effluent from carbon column effleunt.

CE = effluent from cation exchange effluent.

AE = effluent from anion exchanger

(this has been processed in all steps of the pilot plant).

80-gallon and 150,000-gallon floating basins. The 80-gallon basins were constructed of 4 mil transluscent plastic, and suspended in Shagawa Lake from wood-framed polystyrene floats. The 150,000-gallon basins were constructed of nylon impregnated with neoprene and floated with aluminum tubular frames. The top was open and had a surface area of 1,600 square feet. Because only three 150,000-gallon basins were available for use, most of the experiments were performed in the smaller 80-gallon basins.

Following are examples of typical in situ assay experiments conducted from 1967 to 1969 (Brice et al., 1969 and Powers et al., 1972):

(1) Assays in large basins using various treated effluents.

In situ algal assays were performed, using mixtures of Shagawa Lake water or Burntside River water with various amounts of secondary or tertiary (pilot plant) wastewater added. Burntside River water was studied intensively because it is the major source of water for the Lake. These studies included the observation of variations in natural phytoplankton populations (measured by chlorophyll a concentrations) as indices of the effects of wastewaters on the natural lake waters. Secondary wastewater always stimulated algal growth in Shagawa Lake and Burntside River water, whereas tertiary wastewater which had a residual phosphorus concentration of about 0.05 mg/l did not appreciably stimulate algal growth. Results of an experiment on one of the large basins is shown in Fig. 2.

(2) Assays in small basins using secondary treated wastewater or nutrient additions.

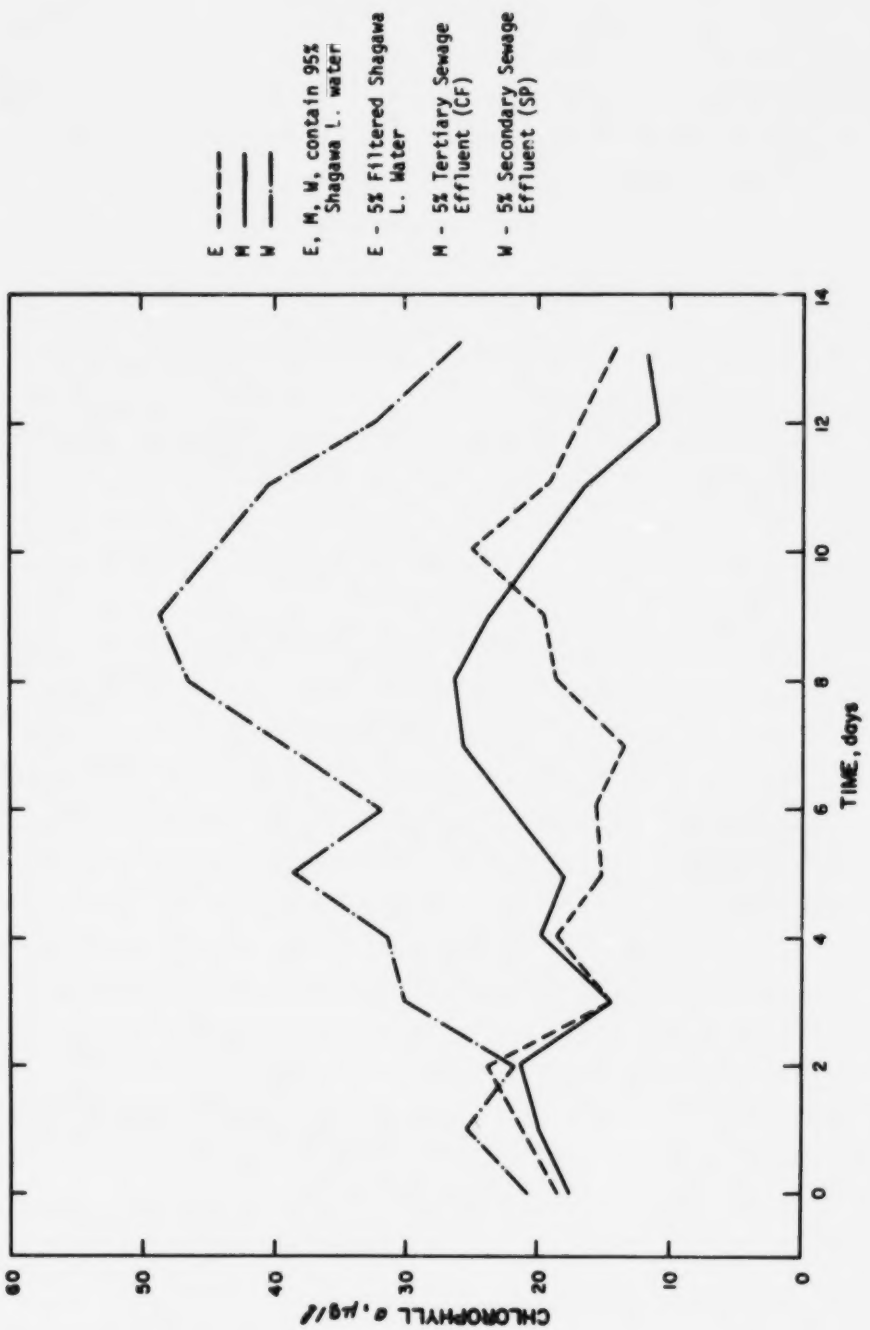


FIGURE 2 Large basin (150,000 gallon) batch-type experiment with chlorophyll a. (From Brice, et al., 1969.)
E = east basin, M = middle basin and W = west basin.

In these experiments, inorganic salts of nitrogen, phosphorus and carbon were added to smaller basins. In the first experiment phosphorus (as K_2HPO_4) was added in concentrations of 0.001, 0.01, and 0.1 mg/l to Burntside River water in separate basins; to another basin was added 2.5 percent by volume of nonfiltered secondary wastewater effluent; and a fifth, control basin, was unmodified. All five basins received 1 percent by volume of Shagawa Lake water to insure an adequate phytoplankton inoculum. A positive algal growth response was obtained only in the container that received secondary effluent (Fig. 3).

In the second experiment, each basin receiving phosphorus also received 1.0 mg N/l as KNO_3. The results strongly indicated that low nitrogen concentrations had been responsible for the lack of algal growth in the first experiment and that, in the presence of abundant nitrogen, the amount of algal growth tended to be in direct proportion to the quantity of phosphorus added (Fig. 4).

The third in situ experiment was performed in the summer of 1970 using Shagawa Lake and Burntside River water (Powers et al., 1972). Nutrient additions included phosphorus, (K_2HPO_4), nitrogen (KNO_3) and carbon ($KHCO_3$) singly and in various combinations. Each control basin contained only lake or river water; however, Burntside River water received 1 percent Shagawa Lake water as an algal inoculum. In Burntside River water (Fig. 5) a positive growth response was elicited only by the addition of nitrogen and phosphorus together. When carbon was included with nitrogen and phosphorus, the response was not as significant. For Shagawa Lake water (Fig. 6), the addition of phosphorus and nitrogen singly, as well as in

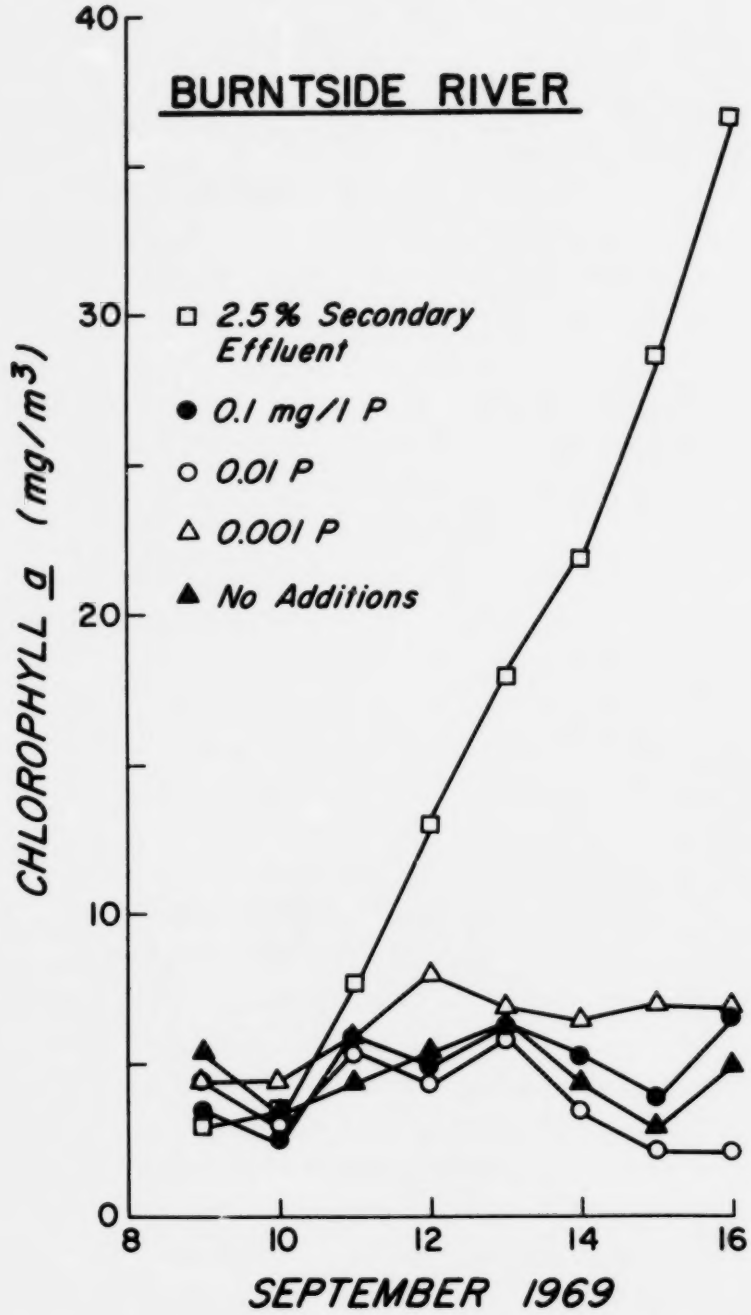


FIGURE 3 Effect of addition of three concentrations of phosphorus and of secondary effluent on chlorophyll a levels in Burntside River water. September 9-16, 1969. (From Powers, et al., 1972.)

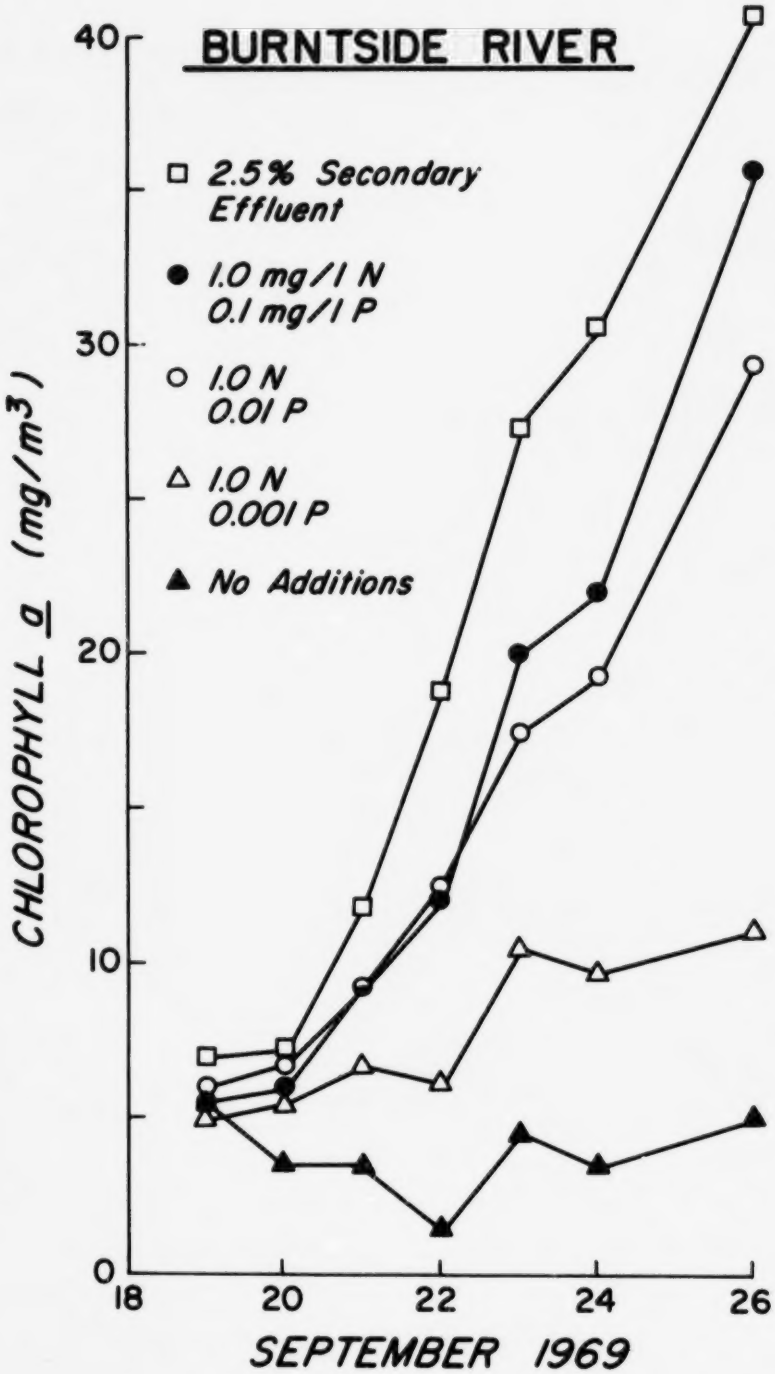


FIGURE 4 Effect of addition of three concentrations of phosphorus with nitrogen, and of secondary effluent, on chlorophyll a. (From Powers, et al., 1972.)

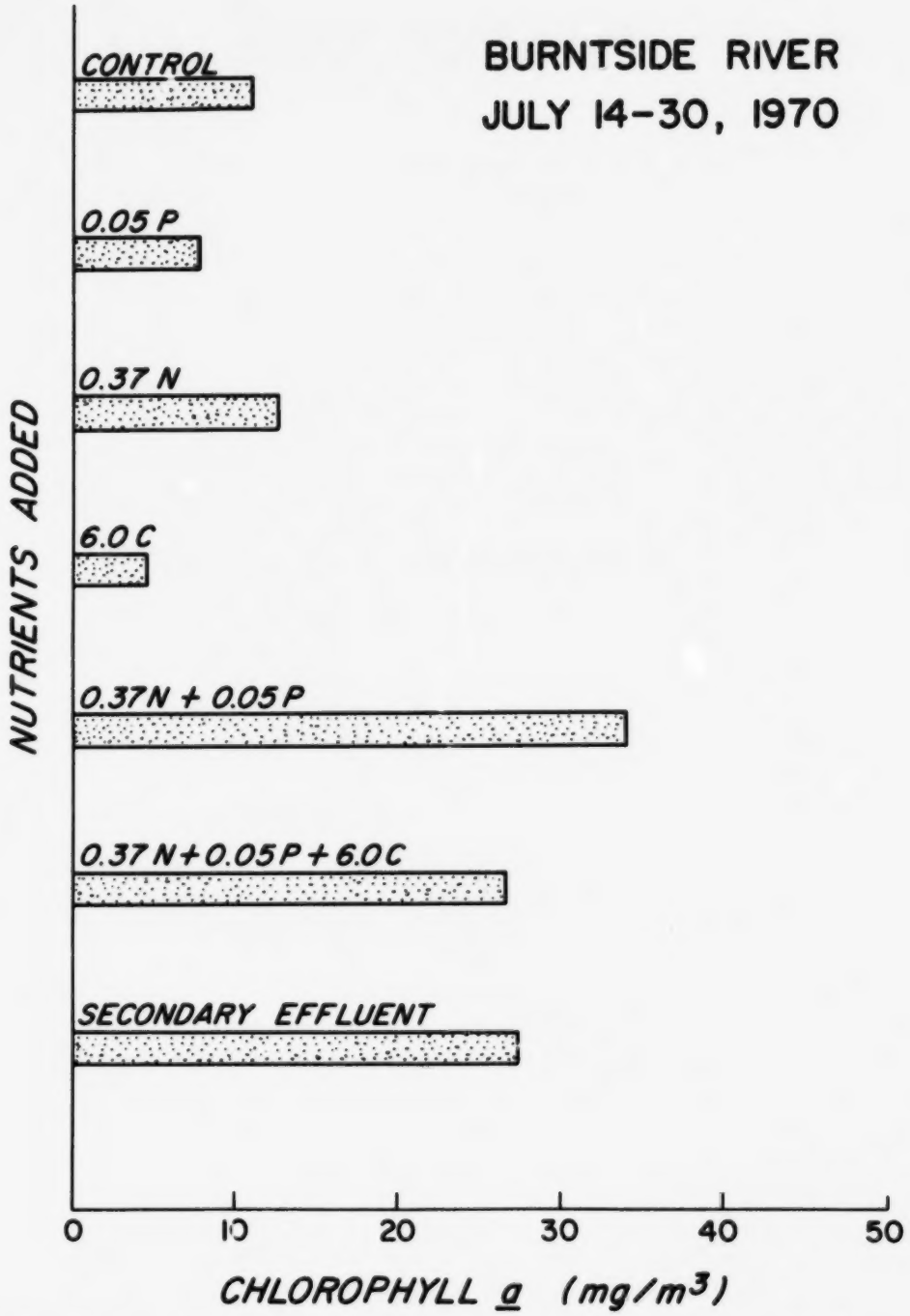


FIGURE 5 Maximum chlorophyll a levels attained in Burntside River water following addition of indicated nutrients. July 14-30, 1970. (From Powers, et al., 1972.)

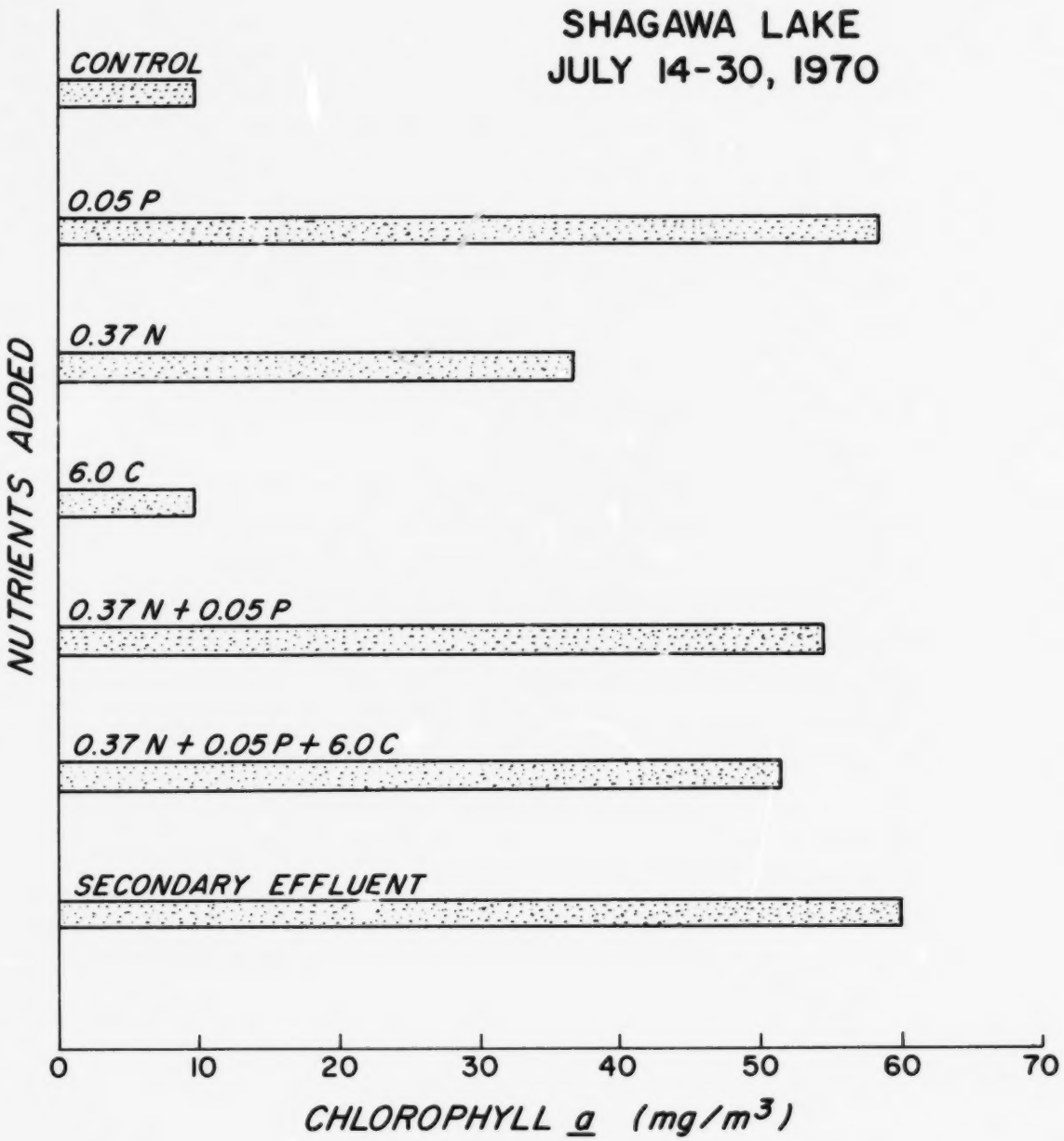


FIGURE 6 Maximum chlorophyll a levels attained in Shagawa Lake water following addition of indicated nutrients. July 14-30, 1970. (From Powers, et al., 1972.)

combination, significantly stimulated algal growth. Stimulation of algal growth by phosphorus alone was greater than by nitrogen alone; and stimulation by nitrogen plus phosphorus was no greater than that resulting from the addition of phosphorus only. Addition of carbon with phosphorus and nitrogen did not stimulate growth beyond that achieved by phosphorus alone or by phosphorus plus nitrogen.

(3) Laboratory algal assays.

Laboratory algal assays were also performed on the various wastewater effluents in combination with the natural waters involved. The results from these experiments demonstrate that effluent from the advanced wastewater treatment plant would not support the growth of the test algae unless phosphorus was added (Fig. 7). Other assays, likewise, showed that effluent from the advanced treatment plant would not support algal growth in Burntside River water whereas, secondary treated effluent, phosphorus, and phosphorus and nitrogen in combination stimulated growth (Fig. 8). While nitrogen was not growth limiting in the natural water, assays showed that it became limiting after phosphorus was added in excess and abundant algal growth had occurred. Further details of these tests are found in Miller and Maloney, 1971.

LIMNOLOGY OF SHAGAWA LAKE

Sampling Program

Chemical, physical and biological parameters of Shagawa Lake have been and continue to be monitored since the start of the project to characterize

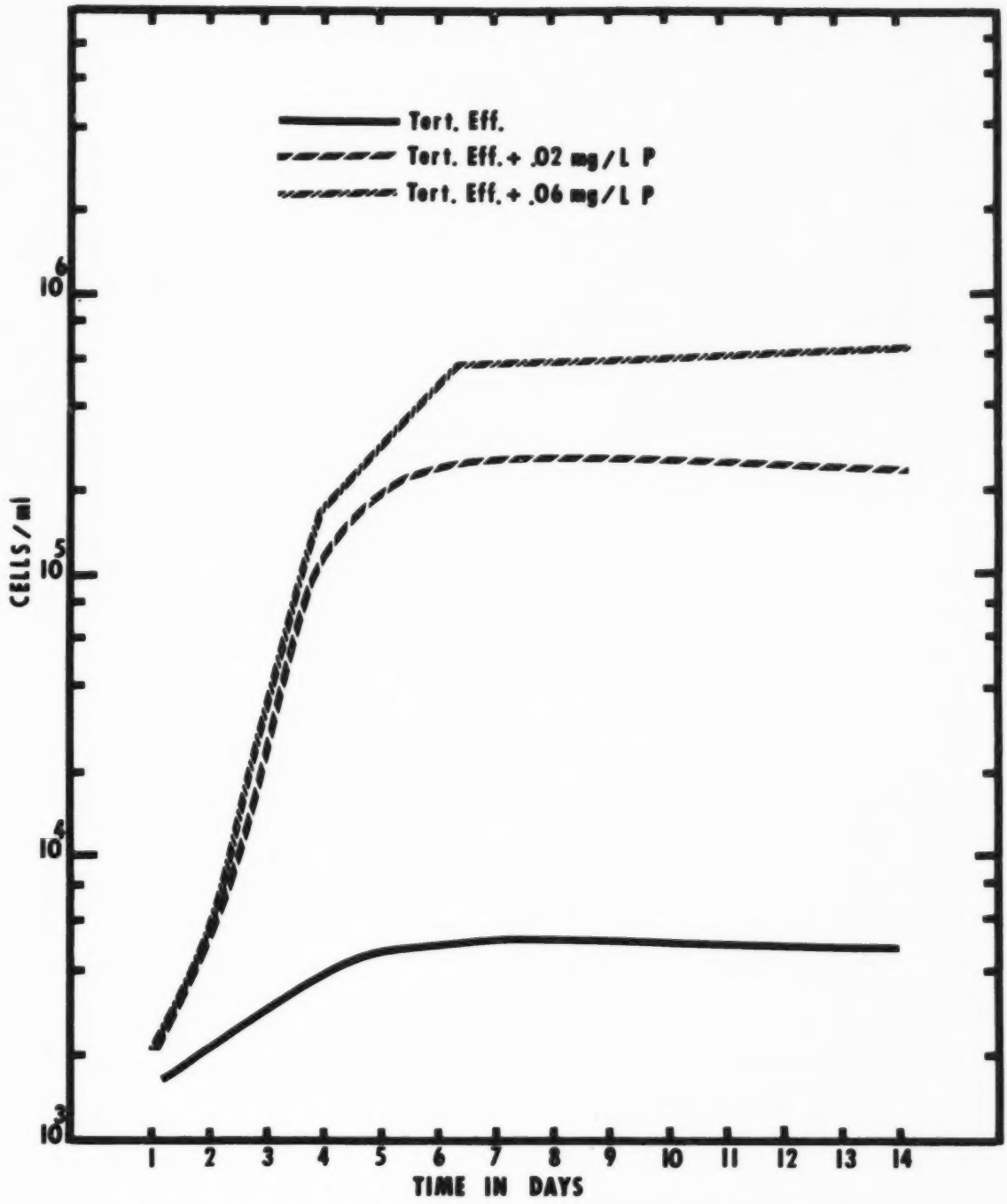


FIGURE 7 Effect of phosphorus additions to tertiary effl ·nt upon the growth response of Selenastrum capricornutum. (From Miller, et al., 1971.)

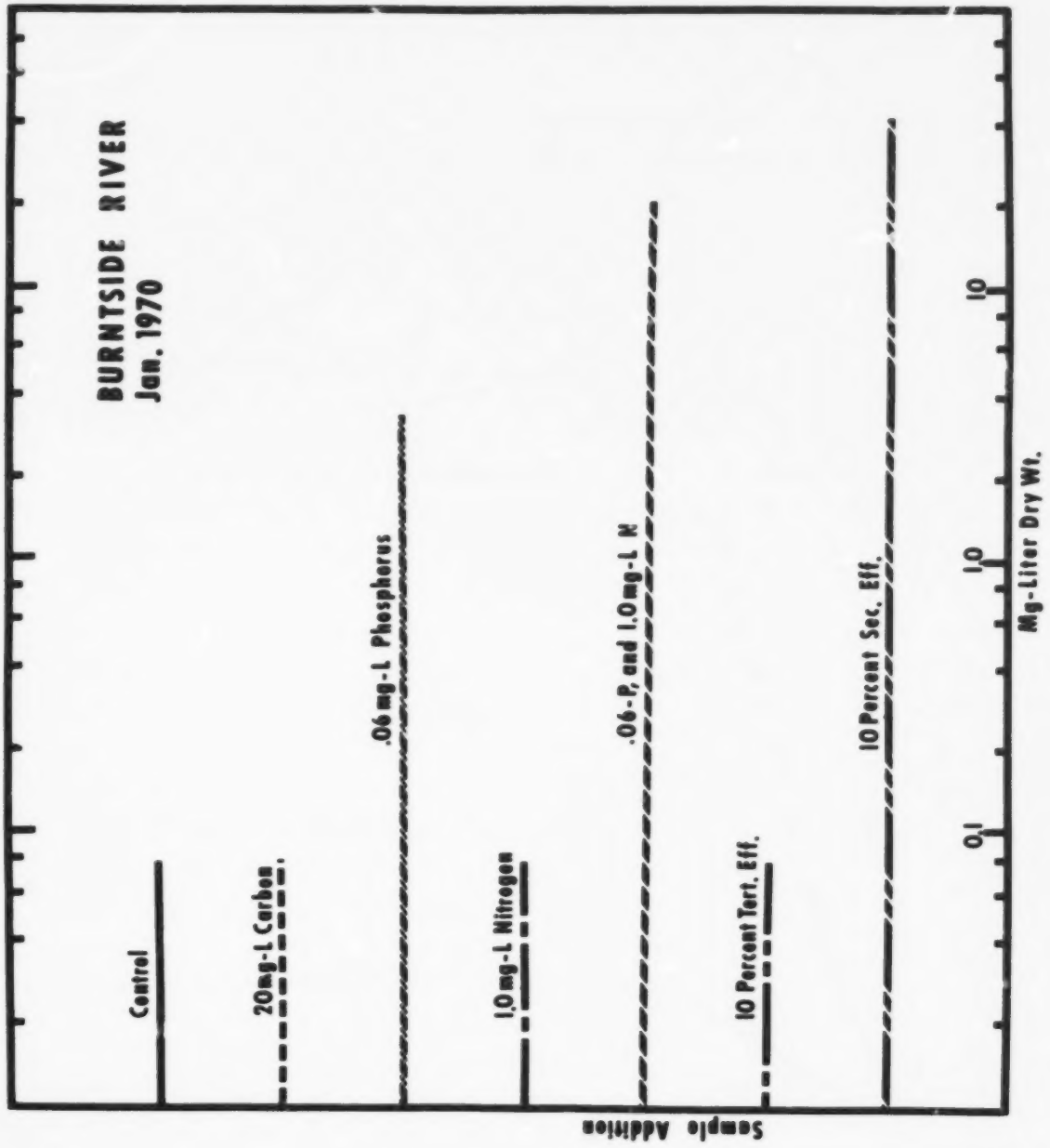


FIGURE 8 Effect of nutrient additions to Burntside River water on the growth of Selenastrum capricornutum. (From Miller, et al., 1971.)

the lake and its tributaries. The objectives of the characterization studies are to: 1) determine the hydrologic and nutrient budgets of the lake, 2) establish conditions in the lake prior to nutrient reduction by advanced wastewater treatment and 3) follow the recovery of the lake after the plant is operational.

Shagawa Lake is presently sampled at Olson's Bay, Brisson's Point and East End Deep Hole (sampling locations shown in Fig. 1). Each station is sampled weekly at the surface and at five-foot intervals to the bottom. Tributaries--Burntside and Shagawa rivers and Armstrong, Longstorff, Burgo, and Bjorkman creeks--are also sampled weekly. The secondary treated wastewater effluent was sampled several times a week until mid-1971 when an automatic system began collecting hourly samples which are composited (flow rated) and analyzed daily. Stinky Ditch, located adjacent to the wastewater treatment plant, receives stormwater runoff and some septic tank seepage. It is sampled on the same regime as the wastewater effluent. In addition, Burntside and Fall lakes are sampled monthly.

Chemical parameters being measured include total and orthophosphate phosphorus; nitrate, nitrite, ammonia and Kjeldahl nitrogen; pH; conductivity; dissolved oxygen; alkalinity and organic carbon. Several times a year samples are also analyzed for sodium, potassium, calcium, magnesium, silica, chloride, sulfate and trace metals (Al, Cu, Pb, Zn, Fe, Mn, Mo, Co, Hg).

Biological measurements include algal and zooplankton counts and identification, chlorophyll and pheo-pigments, primary productivity (light/dark bottle oxygen method), dry weight, and periodic counts and identification of benthos.

Physical measurements include temperature, Secchi disc, light penetration and solar radiation.

Physical Conditions

The annual thermal regime, which has become evident based upon six years of temperature data, is typical of northern United States lakes. An ice cover forms toward the end of November when the surface temperature drops to 0°C; temperatures in the deep holes do not drop much below 4°C, and there is a very gradual increase in temperature with depth throughout the winter season apparently due to a flux of heat through the lake floor.

Ice breakup occurs toward the end of April. Winds cause a complete and rather rigorous turnover and the water temperature subsequently rises. A hypolimnion develops in Shagawa Lake usually in late July or early August in the deep holes. Once developed, the hypolimnion, which usually occurs beneath 30 feet, becomes rapidly anaerobic. Epilimnetic temperatures typically reach 21°C during the summer months, although as a result of extended periods of high temperature, they may attain 26-27°C. Cooling during mid-September causes a second complete turnover of the lake. The water column then remains well mixed until the generation of ice cover.

Specific conductivity typically falls between 50 to 75 µmhos/cm during the period of stratification. Wide ranges in conductivity measurements occur during the iced-over months when surface values are generally below 40 µmhos/cm and values in deeper areas may reach 100 µmhos/cm. Dissolved oxygen in surface waters is generally at the saturation level and supersaturation occurs during periods of intense algal activity. Secchi disc measurements range from a maximum of eleven feet to a minimum of 2 feet, the latter being typical of periods of high algal productivity and standing crops of algae.

Nutrient Concentrations and Algal Conditions

Total phosphorus and total nitrogen concentrations are generally high, typically reaching 0.13 mg/l and 1.3 mg/l, respectively. Orthophosphate and inorganic nitrogen concentrations attain levels of 0.06 mg/l and 0.4-0.5 mg/l, respectively. Chlorophyll a concentrations reach 60-80 µg/l during the peak growing season while productivity rates, as measured by the oxygen production method, typically reach 160 mg $C/m^3/hr$ over a four-hour period at the depth of maximum photosynthesis. Areal productivity rates reach about 200-250 mg $C/m^2/hr$ over the four-hour period.

During the late summer months predominant algae are the blue-greens, Aphanizomenon spp. and Anabaena spp.; greens are present in large numbers throughout the summer months; and diatoms are present in appreciable numbers only during the early spring and late fall.

Hydrologic and Nutrient Budgets

The hydrologic budget of the lake was calculated from tributary flow measurements (by U. S. Geological Survey contract) and rainfall and evaporation data (obtained from the U. S. Weather Bureau). The USGS determined, after drilling numerous test wells, that groundwater was not a significant factor in the water budget. Rainfall was analyzed for the various forms of phosphorus and nitrogen for use in establishing the nutrient budget.

The hydraulic retention time of Shagawa Lake is about 8 months. Burntside River annually contributes about 65 percent of the surface water to Shagawa Lake while contributing only about 10 percent of the phosphorus.

The secondary wastewater treatment plant annually contributes only about 1 percent of the water and about 70 percent of the phosphorus loading to the lake. The average annual input of phosphorus into Shagawa Lake is approximately 16,000 lbs. Of this input, approximately 70 percent is discharged through Shagawa River while 30 percent is lost to the sediments of the lake.

The average annual measured input of nitrogen into Shagawa Lake is about 155,000 lbs. Slightly more nitrogen leaves the lake through Shagawa River, indicating that nitrogen fixation may play a role in the nitrogen budget.

FULL-SCALE LAKE RESTORATION DEMONSTRATION PROJECT

Based on conclusions from the pilot study and the national need to demonstrate that a eutrophic lake can be restored, the Environmental Protection Agency awarded funds to the City of Ely to construct an advanced wastewater treatment plant and provide supplies and services for its operation. For a period of three years the EPA will operate both secondary and tertiary municipal wastewater treatment facilities. The EPA National Environmental Research Center, Corvallis, Oregon (National Eutrophication Research Program) will continue to assess biological, chemical, and physical properties of the lake. The latter will also relate the characterization of the lake after initiation of nutrient removal to the characterization which has been established for the five years prior to nutrient removal.

Overall project management is the responsibility of the Project Chief (Supervisory Research Chemical Engineer) who is a member of the Lake Restoration Section, National Eutrophication Research Program. The

Project employs the following six permanent personnel: Project Chief, Physical Scientist, Sanitary Engineer (plant superintendent), Analytical Chemist, Biological Laboratory Technician, and Administrative Clerk. Twenty-two temporary, full-time personnel are employed: one Aquatic Biologist, twelve Plant Operators and Mechanics, and nine Physical Science or Biological Laboratory Technicians. Three other Plant Operators have been assigned to the Project by the City of Ely. In addition, one Mathematician and one Aquatic Biologist are located in Corvallis for data processing and mathematical modeling. Fig. 9 shows the organizational structure of the Shagawa Lake Project.

Design of the advanced wastewater treatment plant was done by Toltz, King, Duvall, Anderson, and Associates, Inc., Architects and Engineers. The total cost of the advanced wastewater treatment facility is estimated to be $2,870,000 which includes the design, construction and operation of the plant until January 1976. Over 93 percent of the cost was provided by EPA with the remainder from the City of Ely.

The advanced wastewater plant unit processes consist of two chemical treatment stages in series followed by dual-media filtration. Lime precipitation, achieved in the first stage, was selected for Ely wastewater as the most appropriate system to achieve the extremely low phosphorus levels desired while providing a sludge that could be readily dewatered for acceptable land disposal.

The second stage will permit the optional use of alum and/or a polymeric flocculating agent to further reduce the phosphorus to minimal levels. For the two stage system, both solids-contact clarifier units (Wilcox, 1972) are made highly efficient by recirculation of large volumes of previously precipitated solids. These solids act as nuclei to

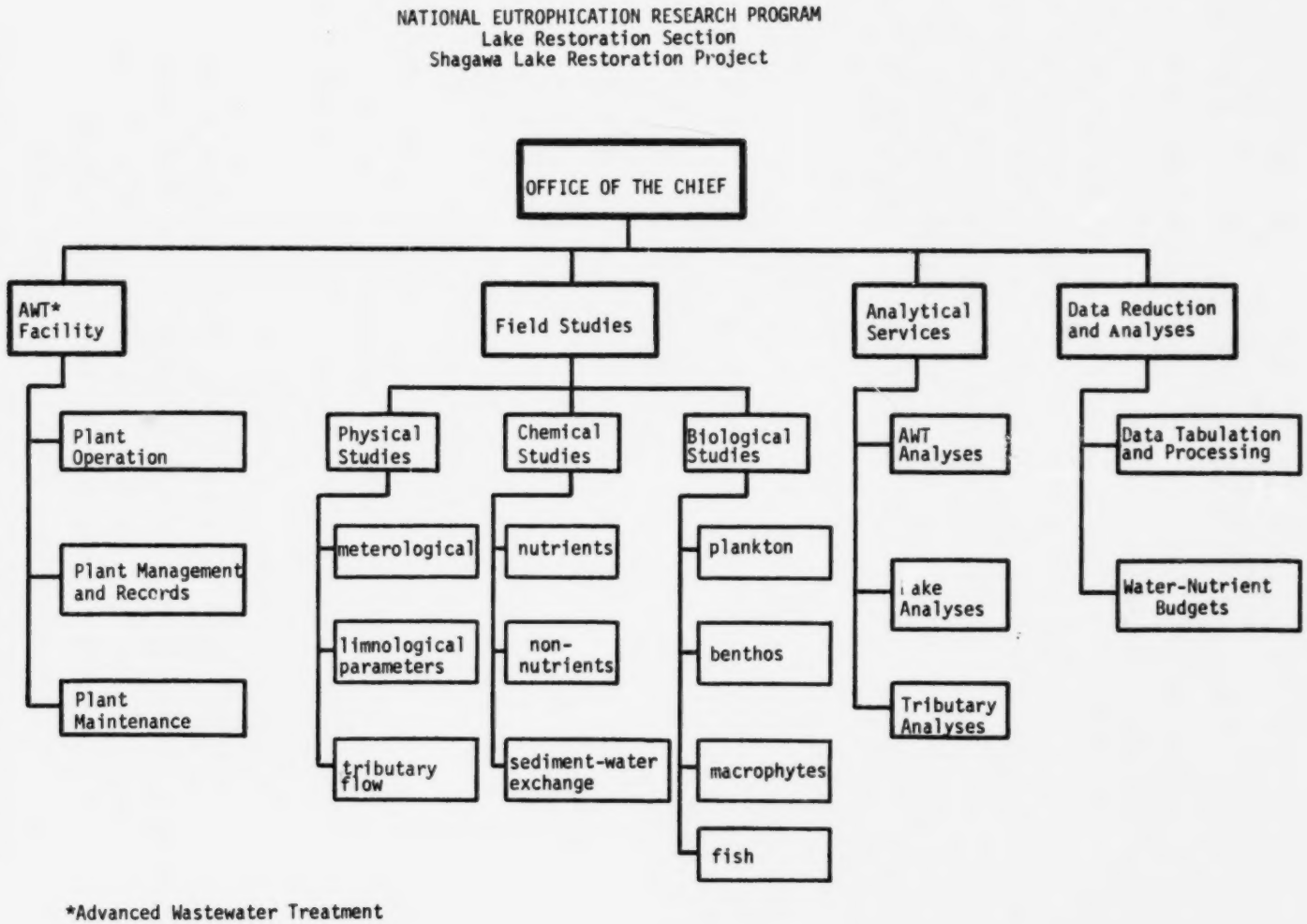


FIGURE 9 Organizational structure of the Shagawa Lake Project.

which newly formed precipitates adhere, creating a smaller number of larger, denser, and more easily settled particles. The clarified effluent from the second treatment stage will go through dual media (anthracite and sand) filters to remove any remaining suspended solids. Underflow sludge from each of two clarifiers will be thickened in a gravity thickener and then dewatered to about 40 percent solids in a rotary-belt vacuum filter before disposal to landfill. The flow diagram for the advanced wastewater treatment plant is shown in Fig. 10.

It is planned that digestor sludge from the secondary plant will also be added to the gravity thickener with the chemical sludge, thus providing acceptable disposal form for all sludges generated. The State of Minnesota Pollution Control Agency has approved disposal of the dewatered sludge in a sanitary landfill site about 12 miles south of Ely.

Chemical feed capability and points of addition are shown in Fig. 11 which is a process diagram for the main treatment units. The reactions for the two-stage treatment system are shown in Fig. 12. The main reaction is that between lime and orthophosphate to form calcium hydroxyapatite. Lime is added to the first clarifier to raise the pH to about 11.5 where calcium carbonate, calcium hydroxyapatite and magnesium hydroxide are formed. At this pH, considerable excess calcium is present in the system. Both the magnesium hydroxide and calcium carbonate precipitates act as flocculants and aid in the removal of the gelatinous calcium hydroxyapatite as well as other solids.

Ely municipal wastewater is quite low in alkalinity and hardness. Although this means relatively little lime is required to complete the reactions, it also means that the resultant calcium carbonate and magnesium

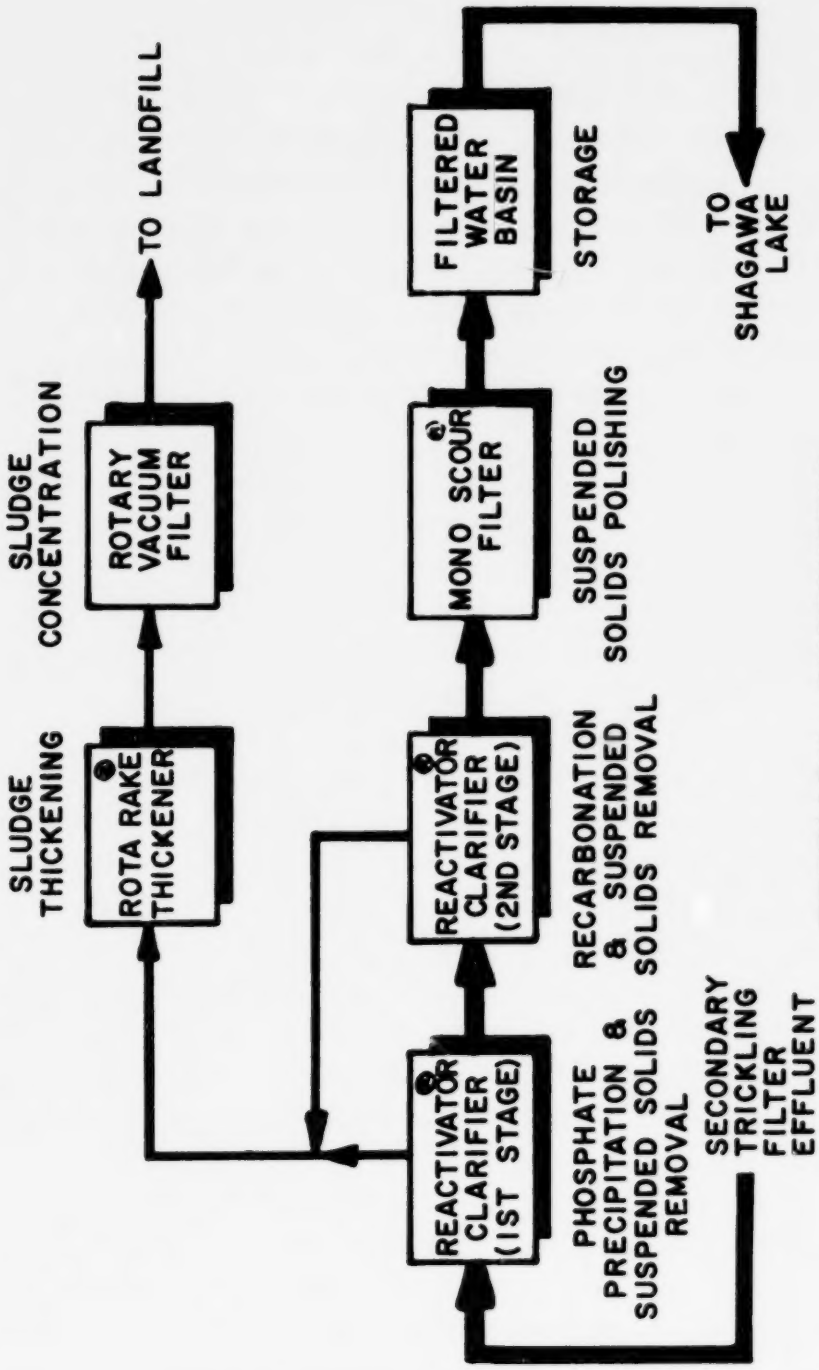
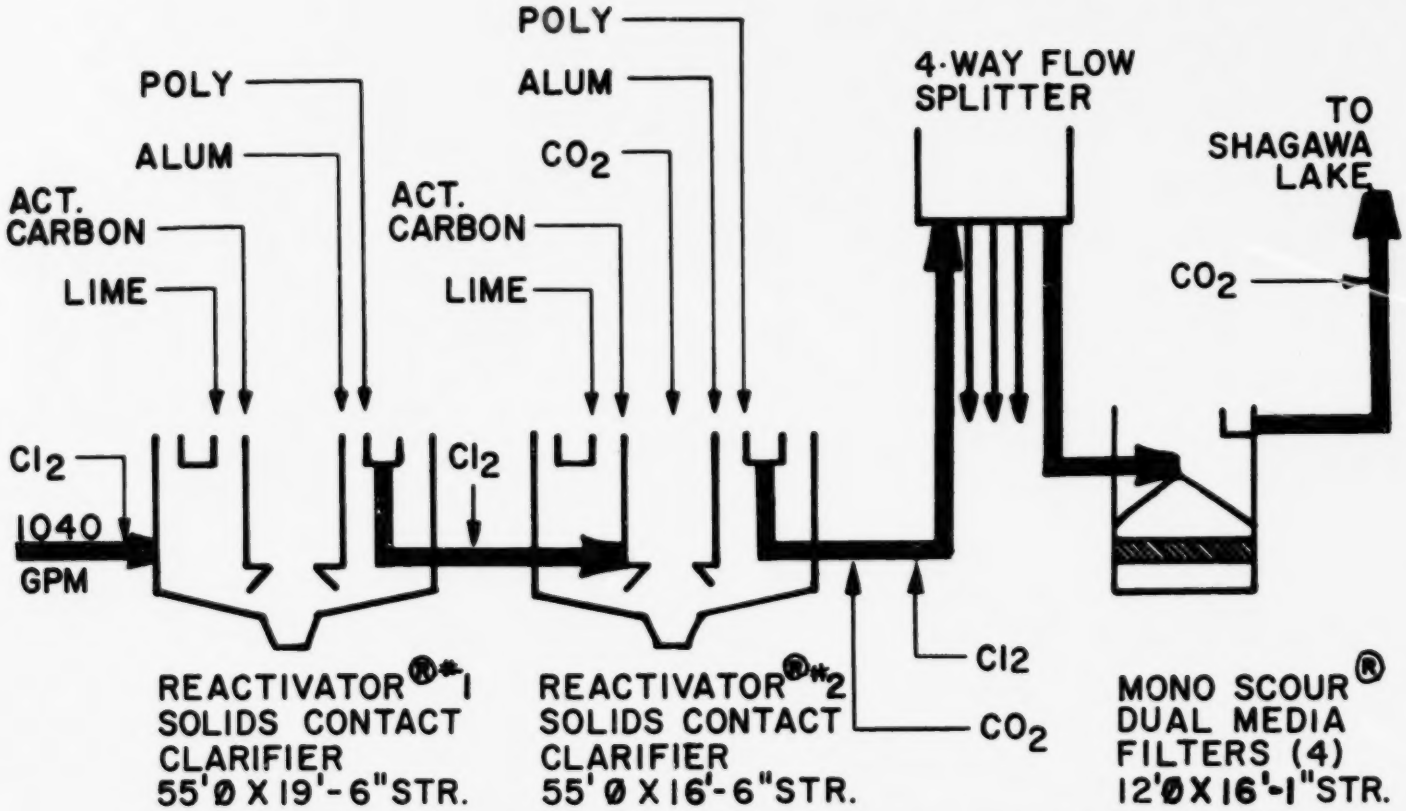


FIGURE 10 Flow diagram.(From Wilcox, 1972.)



PROCESS DIAGRAM • MAIN TREATMENT UNITS
TERTIARY PHOSPHORUS REMOVAL PLANT
ELY, MINNESOTA

FIGURE 11 Process diagram. (From Wilcox, 1972.)

REACTIONS IN SOLIDS-CONTACT CLARIFIER #1.

$$5Ca(OH)_2 + 3PO_4^{-3} \rightarrow \underline{Ca_5(OH)(PO_4)_3} + 9OH^-$$

$$Ca(OH)_2 + HCO_3^- \rightarrow \underline{CaCO_3} + OH^- + H_2O$$

$$Mg^{+2} + 2OH^- \xrightarrow{pH>11} \underline{Mg(OH)_2}$$

REACTIONS IN SOLIDS-CONTACT CLARIFIER #2.

$$Ca^{+2} + 2OH^- + CO_2 \rightarrow \underline{CaCO_3 + H_2O}$$

LIME TREATMENT

FIGURE 12 Lime reactions. (From Wilcox, 1972.)

hydroxide precipitates cannot be expected to completely flocculate the calcium hydroxyapatite. Therefore, a polymeric flocculating agent is used as a coagulant aid. Solids are removed from the bottom of the clarifier unit while the clear water flows by gravity to the second unit for further phosphorus reduction.

In the second clarifier unit, carbon dioxide is added to remove excess calcium as indicated by the last equation of Fig. 12. The calcium carbonate thus formed will provide a second flocculation step. Recarbonation will also help lower the pH to a desirable range for discharge. Alum addition can be used to remove any phosphorus that is liberated due to the pH reduction from addition of carbon dioxide in the second clarifer. Activated carbon may be added to one or both of the clarifiers to remove organic compounds.

The wastewater treatment facilities are operated and monitored 24 hours a day, 7 days a week to achieve the desired project objective. Complete laboratory capabilities have been established as part of the monitoring process of the plant's operation.

MODELING OF SHAGAWA LAKE DATA

In an attempt to understand the mechanisms which control the eutrophic process in Shagawa Lake, a mathematical model will be developed. Test of the model response against field data collected from the Shagawa Lake system will provide a mechanism by which judgments can be made concerning the understanding of the eutrophication process.

The background data obtained from the Shagawa Lake system offers an ideal opportunity to test presently held concepts of the eutrophication process.

In addition, the advanced wastewater treatment plant will reduce the phosphorus input to the system very appreciably; a manipulation of this sort offers an excellent chance to test concepts against observed changes within the system.

One of the major purposes of the modeling is to identify various components of the phosphorus cycle within the lake system. Various elements (compartments) within the lake and relationships between these elements will be defined. For the purposes of this study, the elements are indicated as boxes (Fig. 13); the arrows indicate predominant direction of flow of phosphorus. For example, orthophosphate may be consumed by algae which may in turn, die, be acted upon by decomposers to produce orthophosphate, or be eaten by herbivores. These elements and processes are internal to the lake system.

In addition, several factors which are external to the system acting as sources or sinks for various elements will be studied. For example, the amount of orthophosphate which is contributed by tributaries and wastewater treatment plant effluent can be varied in the model. Similarly, the sediments and outflow tributary which act as sinks for phosphorus can also be simulated using the model.

Models of several levels of complexity are envisioned. Initially, an attempt will be made to account for the observed concentrations of the various forms of phosphorus (inorganic phosphorus, algal phosphorus, total phosphorus) within the lake based upon the rates of input and output from the system without trying to incorporate processes within the system. The goal of this phase of the project is to establish a phosphorus nutrient budget and to determine what proportion of the nutrient budget can be accounted for by the wastewater input. A similar scheme will be prepared for the nitrogen cycle.

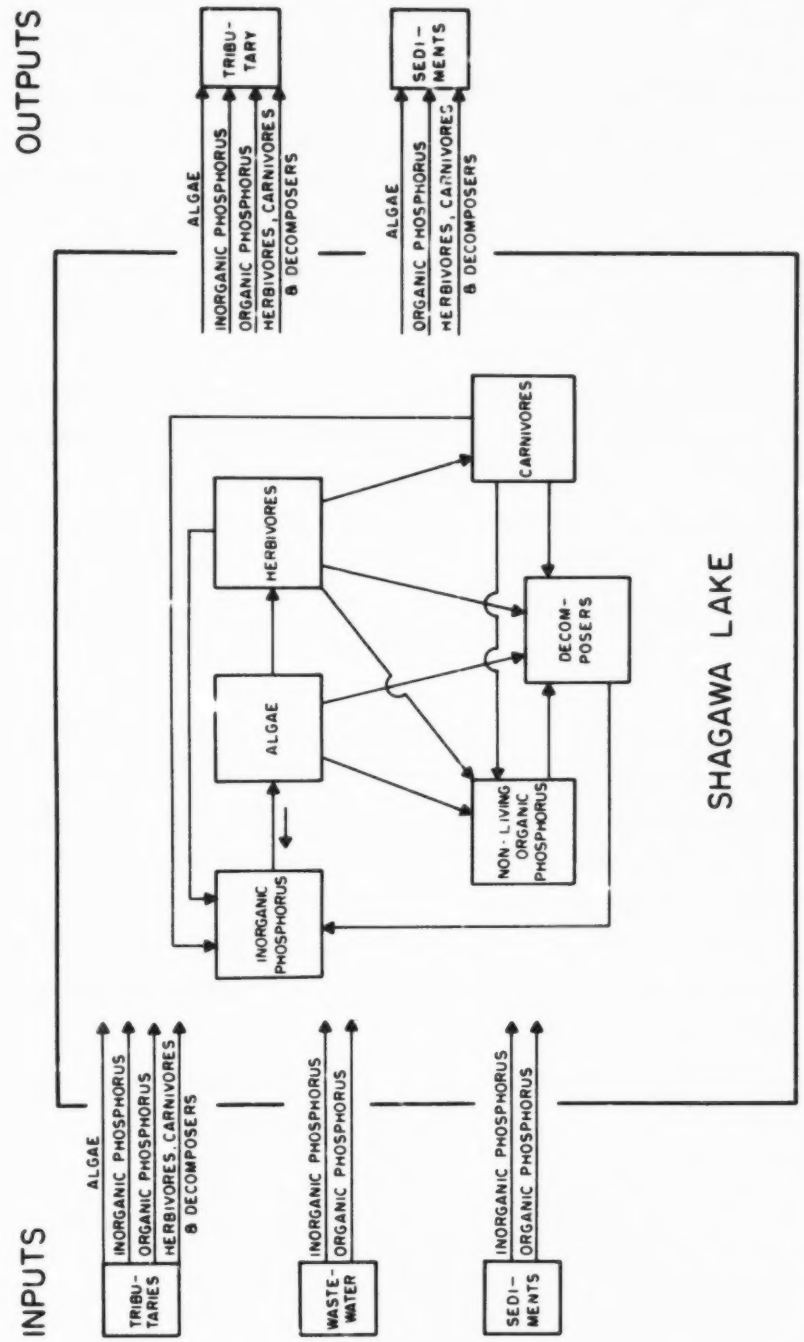


FIGURE 13 Model of phosphorus cycle in Shagawa Lake. Boxes indicate reservoirs of phosphorus, arrows indicate predominate direction of flow.

The first model will be simple, i. e., in the form of a differential equation relating time change of concentration of phosphorus within the lake to inputs and outputs. This model can be used to simulate the effect of decreasing the phosphorus input upon initiation of phosphorus removal by advanced wastewater treatment. The measured time varying inputs and outputs will be incorporated into the differential equation.

A model of greater complexity will be developed to incorporate those processes within the lake which are considered important. Mathematical relationships will be developed to describe as well as possible the relationships identified in Fig. 13. A mechanistic approach will be used wherever possible. For example, the rate of growth of algae will be related to light, temperature, and the concentration of growth-limiting nutrients (inorganic phosphorus and inorganic nitrogen).

After the various mathematical relationships have been identified and incorporated into a model, a comparison with the lake system will be made in an attempt to validate the model. The sensitivity of the model output will be tested against variation in parameters identified for different relationships to determine which have greatest effect upon the model output. Manipulations such as the decrease in phosphorus input upon completion of the treatment plant will be simulated and results compared with data collected during the next several years.

SUMMARY

1. A research project has been initiated by EPA to demonstrate lake restoration by nutrient removal (primarily phosphorus) from wastewater effluent while permitting such treated effluent to continue to flow into the lake.

2. Shagawa Lake, at Ely, Minnesota, was chosen for this demonstration because of its near ideal study characteristics.

3. Advanced wastewater treatment pilot plant studies were conducted showing that phosphorus can readily be removed.

4. Algal growth potential studies were conducted demonstrating that the chemical treatment processes of the pilot plant were effective in controlling algal blooms in the receiving waters.

5. A full-scale, advanced wastewater treatment plant has been designed and constructed and will be operated under EPA supervision until January 1976. Nutrient removal in the plant is primarily by chemical precipitation with lime. The estimated cost of the plant, including operation, and monitoring for three years is $2,870,000.

6. A three-year program has been developed to evaluate the effectiveness of the plant and to demonstrate the recovery of the lake.

7. Mathematical modeling studies have also been initiated to help understand the mechanisms which control the eutrophic process in Shagawa Lake.

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APPENDIX

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APPENDIX

1. Pilot plant prior to completion.

2. Pilot plant building.

3. Secondary wastewater treatment plant.

4. Beginning construction of the advanced wastewater treatment (AWT) plant.

5. Construction of the AWT plant.

6. Basic shell of AWT plant showing lime hoppers.

7. Basic shell of AWT plant.

8. Construction of AWT plant near office/laboratory area.

9. Construction of AWT plant nearing completion.

10. AWT plant nearing completion.

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12. Aerial view of Shagawa Lake and City of Ely showing 150,000 gallon *in situ* basins.

13. 150,000 gallon basin and project weather station.

14. Series of 80 gallon basins.

15. Sampling one of the 80 gallon basins.

16. Instrumentation used in limnology monitoring of Shagawa Lake.

17. Lake monitoring during the winter; equipment sled is pulled by a snowmobile.

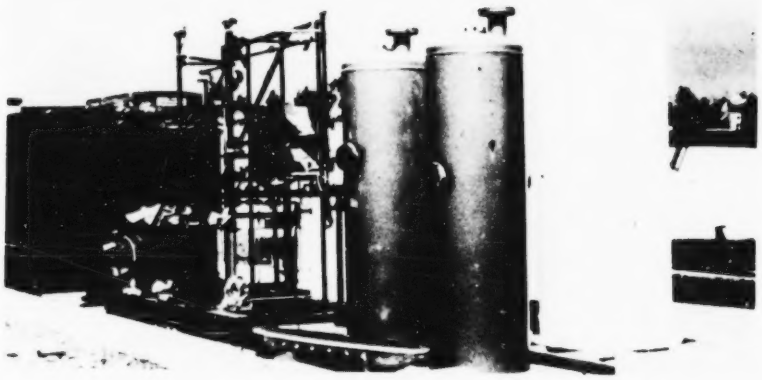
18. Lake sampling through the ice.

19. Southwest section of lake showing Longstorff and Armstrong creeks in foreground and Burntside River in upper left.

20. Burntside River with Shagawa Lake/Ely in background.

21. Staff gage measurement of Bjorkman Creek.

22. Office/laboratory building.



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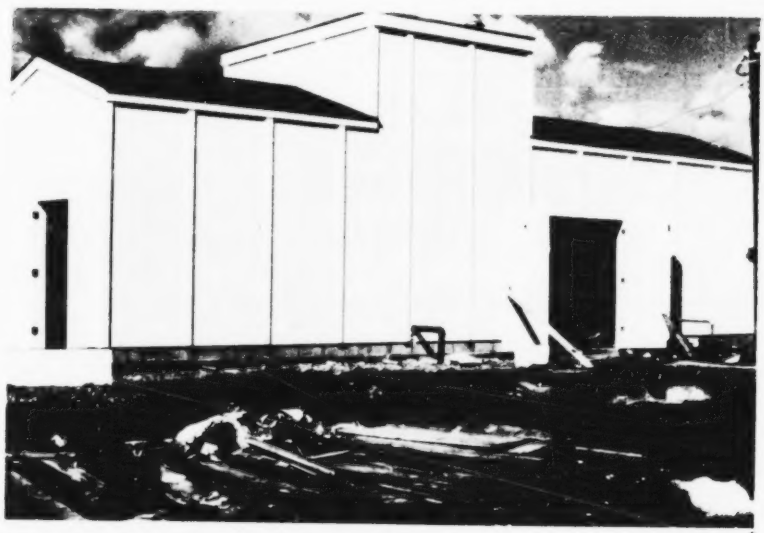

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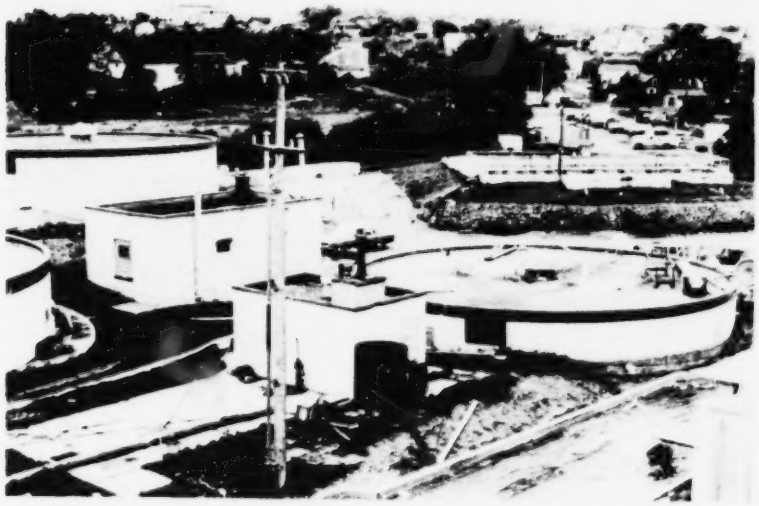

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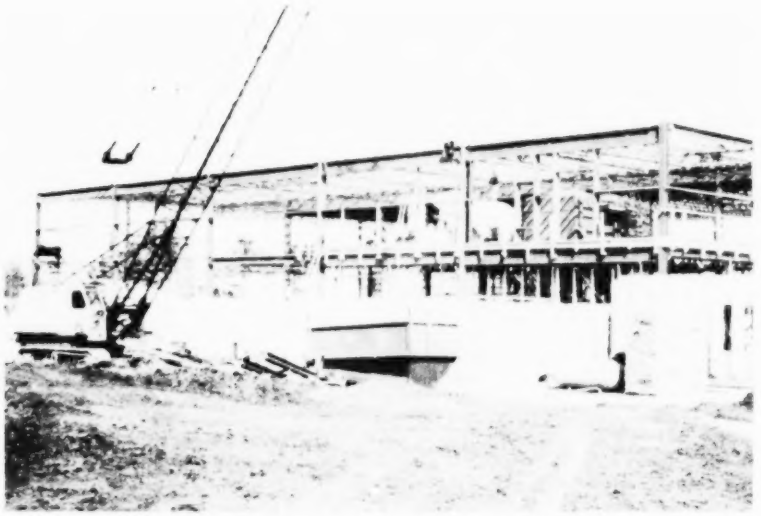

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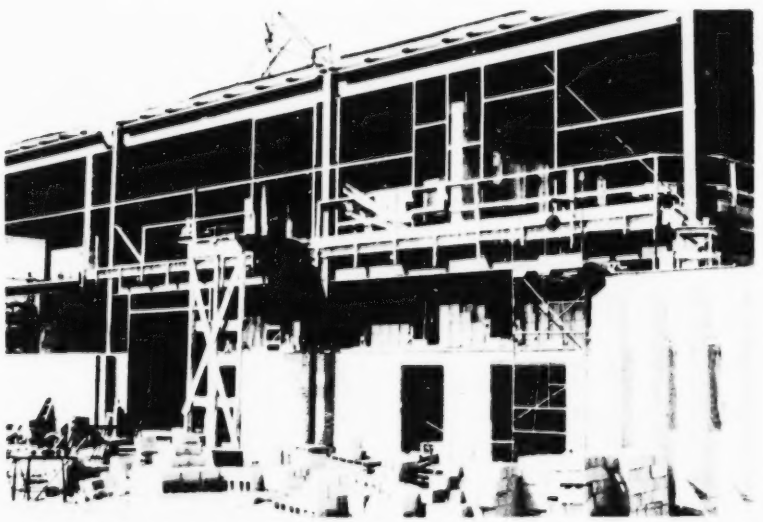

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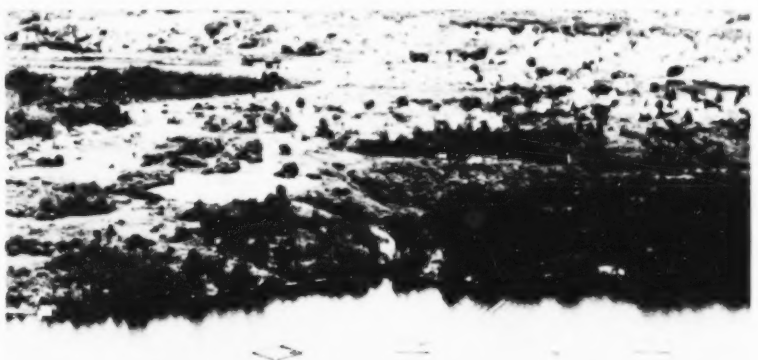

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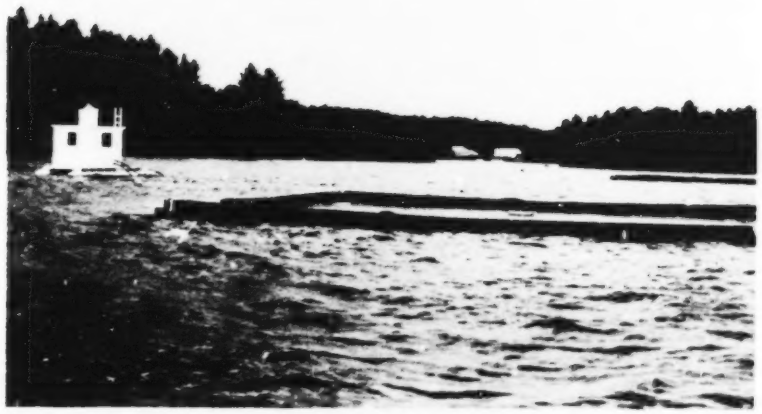

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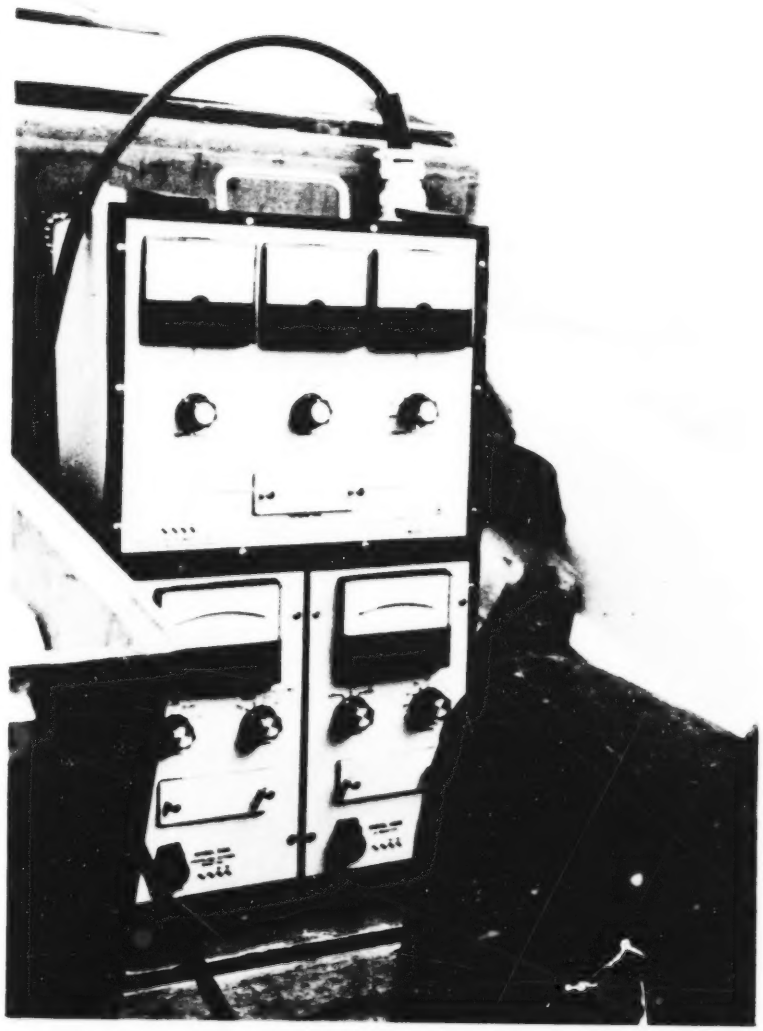

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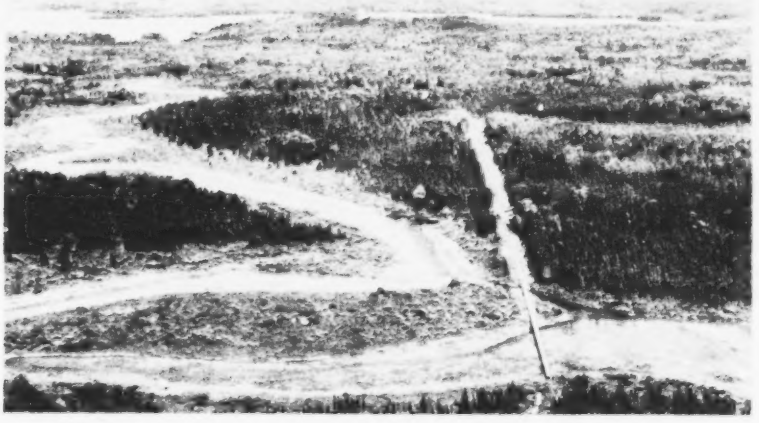

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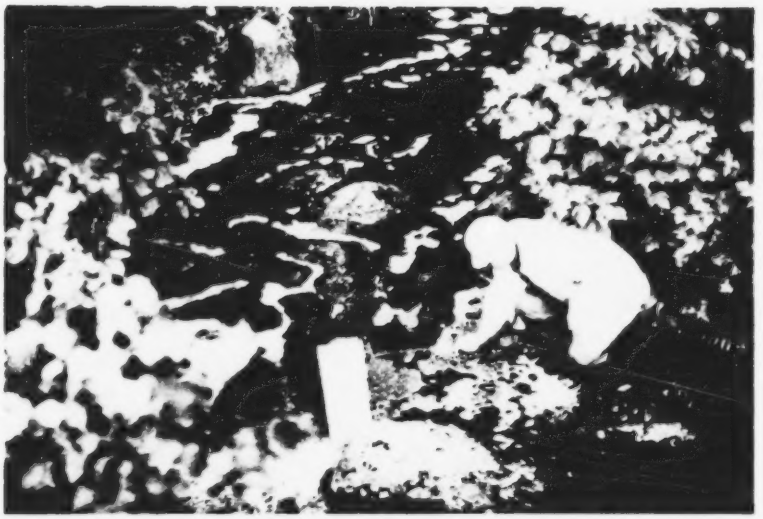

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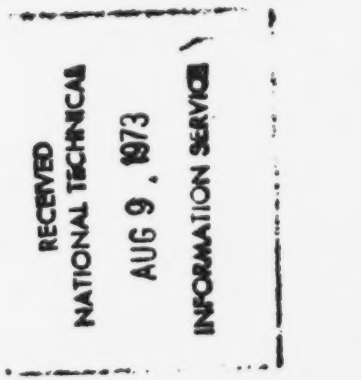

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